AD-A139 528 BIOTECHNOLOGY PREDICTORS OF PHYSICAL SECURITY PERSONNEL PERFORMANCE: CERE..(U) NAVY PERSONNEL RESEARCH AND DEVELOPMENT CENTER SAN DIEGO CA D B MALKOFF FEB 84 1/1

UNCLASSIFIED NPRDC-TR-84-23 MIPR-83-507 F/G 5/10 NL

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NPRDC TR 84-23 February 1984

# BIOTECHNOLOGY PREDICTORS OF PHYSICAL SECURITY PERSONNEL PERFORMANCE: CEREBRAL POTENTIAL MEASURES RELATED TO STRESS

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| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER<br>NPRDC TR 84-23 | 2. GOVT ACCESSION NO.<br>AD-A139 528 | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>BIOTECHNOLOGY PREDICTORS OF PHYSICAL SECURITY PERSONNEL PERFORMANCE: CEREBRAL POTENTIAL MEASURES RELATED TO STRESS | | 5. TYPE OF REPORT & PERIOD COVERED<br>Special Report |
| | | 6. PERFORMING ORG. REPORT NUMBER<br>41-83-04 |
| 7. AUTHOR(s)<br>Donald B. Malkoff | | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Navy Personnel Research and Development Center<br>San Diego, California 92152 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>62715H<br>MPR-83-507 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Navy Personnel Research and Development Center<br>San Diego, California 92152 | | 12. REPORT DATE<br>February 1984 |
| | | 13. NUMBER OF PAGES<br>29 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) | | 15. SECURITY CLASS. (of this report)<br>UNCLASSIFIED |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Stress
Performance measurements
Evoked fields
Event-related fields
Event-related potentials

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The research literature related to stress, personality measurements, electrical and magnetic measurements of brain activity, and stress task-protocols was reviewed to determine whether measurements of brain activity can be used to predict job performance under conditions of stress. Results indicated that brain activity measurements show great promise (1) for predicting general response-tendencies of individuals when subjected to stress and (2) as an investigative method for learning more about brain function. Recommendations were made for a research protocol for ascertaining whether measurements of brain activity can be used to predict job performance under stress.

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S/N 0102-LF-014-6601

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# FOREWORD

This effort was conducted within Defense Nuclear Agency (DNA) program element 62715H (Nuclear Weapons Physical Security Research and Development). The objective of the project is to determine the feasibility of using biotechnology procedures such as bioelectric and biomagnetic recordings of brain activity to improve predictions of physical security personnel reliability and performance effectiveness.

This report is the third in a series resulting from this project. Previous reports provided an annotated bibliography (NPRDC TN 83-9) of the stress literature related to performance and reviewed selected experimental procedures for assessing performance under stress (NPRDC SR 84-9). This report concerns predicting responses to stress using bioelectrical and biomagnetic measurements of brain activity. The problems, advantages, and future implications of this research approach are examined, and recommendations are made regarding implementation. The results should be of interest to the research community concerned with brain functions, human behavior, and performance prediction.

Previous research conducted by the Navy Personnel Research and Development Center on brain event-related potentials is summarized in NPRDC TR 84-3.

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# SUMMARY

## Problem

Improved capabilities are desired for measuring and predicting the dependability and performance effectiveness of Navy personnel assigned to security force duties within the nuclear weapons safeguards area, particularly under conditions of stress. Information is needed as to the feasibility of using electrical and magnetic measurements of brain activity (evoked and event-related potentials) for this purpose.

## Purpose

The purpose of this effort was to determine whether measurements of brain activity can be used to predict job performance under conditions of stress.

## Approach

1. The research literature related to stress, personality measurements, electrical and magnetic measurements of brain activity, and stress task-protocols was reviewed.

2. A research protocol was devised that should be useful in ascertaining whether or not measurements of brain activity can be used as predictors of performance under conditions of stress.

## Results and Conclusions

Use of brain activity measurements shows great promise as (1) a tool for predicting general response-tendencies of individuals when subjected to stress and (2) an investigative method for learning more about brain function, particularly as it applies to emotions, human behavior, and individual differences.

## Recommendations

Recommendations were made for a research protocol for ascertaining whether measurements of brain activity can be used to predict job performance under stress.

## CONTENTS

# INTRODUCTION

## Problem

The Navy has been interested in developing the ability to predict more reliably the performance of those individuals whose jobs might subject them to acute or chronic "stress." Security guards and aviators are examples of personnel whose performance under stressful conditions can be of crucial importance. Information is needed to determine whether or not electrical and magnetic measurements of brain activity can be used to differentiate individuals who will perform "well" under stress as opposed to those who will perform "poorly," and, if so, to determine how best to conduct such measurements.

## Purpose

The purpose of this effort was to determine whether measurements of brain activity can be used to predict performance under conditions of stress.

## Background

Previous work at NAVPERSRANDCEN has been directed toward predicting on-the-job performance of individuals by analyzing measurements of their electrical and magnetic brain activity (Lewis, 1983a, 1983b). The bioelectrical measurements have included recordings from subjects of both the spontaneous electroencephalogram (EEG) and the evoked potentials (EPs), in some cases referred to as event-related potentials (ERPs). ERPs differ from EPs in that they result, in part, from internal stimuli, such as cognitive tasks and emotions, rather than from external stimuli alone. The corresponding biomagnetic measurements are the magnetoencephalogram (MEG) and the evoked fields (EFs) or event-related fields (ERFs).

Both EPs and EFs are obtained by presenting to the subject a train of brief stimuli; for example, flashing lights or auditory clicks. The electrical and magnetic activity that are thereby generated within the brain are measured over various areas of the scalp following each stimulus. The activity is averaged together in such a way that random background electrical and magnetic activity, or "noise," is eliminated. The recording of the brain activity "signal" directly resulting from the stimulus is thereby enhanced. The amplitude and latency of this activity may then be analyzed statistically or displayed topographically so as to detect differences between individuals, between separate brain areas, or in the same brain area of an individual at different periods of time.

Ordinarily, the patterns evoked in a specific individual by a stimulus presented under controlled conditions are relatively stable (Hillyard, Picton & Regan, 1978). Measurements of EPs from different subjects, however, even when obtained over the same area of brain and under the same controlled conditions, show significant differences in amplitude and latency patterns (Shagass, 1972b). Because of the considerable evidence in the literature suggesting that specific brain functions tended to be localized to either the left or right brain hemispheres (Gordon, Silverberg-Shalev, & Czernilas, 1982; Kinsbourne, 1978), the Navy Personnel Research and Development Center conducted a number of projects to determine whether ERPs could be used to estimate a subject's potential for mastering certain kinds of skills and, hence, predict his job performance (see Lewis, 1983b).

EPs and ERPs, although relatively stable, do show significant changes as a result of alterations in the internal environment (McCallum, 1979), such as occurs with cognition. Moreover, the changes tend to follow a stereotyped pattern dependent upon the particular environmental change (Begleiter & Porjesz, 1975). Changes such as these can be detected by sequential measurements, consisting of baseline (static) ERPs or EPs, followed by another measurement reflecting the change in a single environmental factor. Such dynamic studies offer exciting research possibilities for the following reason: A single, standardized stimulus such as a flashing light can result in different EP patterns in two individuals. It can be shown, at least empirically, that the patterns have predictive value regarding some aspects of brain function that are involved in job performance. It may be inferred that the different patterns reflect actual differences in the neurophysiological handling of the stimulus and that this, in turn, is correlated with the subject's unique pattern of behavior or skills, at least as it applies to the job in question. If there is some validity to this inference, then the same paradigm could conceivably be applied successfully to other more complex (and even adverse) stimuli in the cognitive (thought processes) and affective (emotional processes) realm, in order to gauge their possible impact upon the subject's future job performance under those same stimulus conditions. There is already ample evidence that cognitive processes profoundly affect EPs (Donchin, Ritter, & McCallum, 1978).

## APPROACH

1. The research literature related to stress, personality measurements, electrical and magnetic measurements of brain activity, and stress task-protocols was reviewed.

2. A research protocol was devised that should be useful in ascertaining whether or not measurements of brain activity can be used as predictors of performance under conditions of stress.

## RESULTS

### Stress and Job Performance

#### Individual Differences

One individual might behave quite differently than another when both are subjected to the same kind of stressful situation (Hokanson, 1969). One individual might "rise to the occasion" and manifest the ability to cope with and resolve the stress-producing problem, another might perform inadequately or indecisively, while still another might show marked deterioration during stress and literally "fall apart." Whatever the nature of the response, "good" or "bad," effective or counterproductive, it is generally consistent for a given individual, particularly over a short period of time under controlled conditions. Even the terminology used by researchers reflects this observation. In conditions of chronic stress, researchers tend to classify individuals according to their most vulnerable body organ-system, whose dysfunction most severely reflects the effects of the stressor. For example, patients are referred to as "ulcer-prone," "coronary-prone," or "neurodermatitis prone" (Ursin, 1978). Likewise, in acute stress, they tend to classify individuals according to the most prominent emotion they manifest. For example, patients are referred to as "anxiety-prone," "prone to withdrawal," or "having great emotional strength or stability" (Grings & Dawson, 1978). These classification tendencies imply that a

significant degree of consistency exists in a person's repertoire of behavioral responses to stress.

On the other hand, it is also commonly accepted that, over a period of time, a given individual's response to the same stressor can vary significantly in terms of both form and intensity. The degree of intra-individual variability is usually attributed to "conditioning factors," such as the individual's age, genetic makeup, gender, diet, drug intake, pre-existing diseases, and physical and social surroundings; in short, the sum total of his internal and external environment (Selye, 1974). When the response changes, the individual is said to have "adapted," "changed coping mechanisms," "responded to therapy," or been subjected to new or changing stressors (McGrath, 1970b).

### "Good" and "Bad" Responses

In view of the complexity of the underlying "conditioning factors" that can mold an individual's final response to a stressor, it is not surprising that there are so many different ways in which individuals in a group vary in their behavior in what appears to be an identical stressful situation. Those resultant responses are often subjected to judgments as to whether they are "good" or "bad" in quality and intensity. Obviously, such judgments are themselves quite subjective--a good response might be good for society or for an employer but bad for the individual, and vice versa (McGrath, 1970a). The soldier who sacrifices his life for his country is said to have served his country well and to have performed (responded) in a good and honorable manner. From the point of view of prolonging his life, however, the response was certainly far from optimum. On the other hand, if detailed information were available about the soldier's psychological makeup and social background, it might well be that his response, even from his personal point of view, was a "good" one. For example, if he felt that such a sacrifice of life was the only response that could lead to the preservation of countless other lives and of ideals that were of far greater importance to him than his own survival, then his dying might well be the optimal response for him personally. Regarding responses to stressors, judgments of good or bad are purely relative, and they are often quite difficult to make.

To predict on-the-job performance of personnel assigned to critical positions, such as security guards, value judgments must not only be made, but must be made before a life-threatening situation occurs.

### Predicting Future Job Performance Under Stress

From a practical standpoint, one cannot subject job applicants to real life-threatening situations to assess their qualifications. Paper-and-pencil aptitude tests have been criticized as being ineffective in predicting on-the-job performance (Ghiselli, 1966). However, since the response of personnel in critical positions can be of corresponding critical importance, the possible application of any technique that shows promise in predicting future behavior under stress must be explored. As noted previously, one such technique is ERP/EP measurements, provided that there is an acceptance of the premise that stress, and behavioral responses to stress, are at least in part mediated by central nervous system pathways (the brain) and are thereby accessible to ERP/EP probing.

## Stress, Behavior, and the Brain

One has little choice but to acknowledge the role of the brain in mediating behavior of any kind. After all, motor activity, sensory activity, cognition, autonomic activity, circadian rhythms, emotionality, hormonal activity, and the coordination among them all

are either dominantly controlled by or, at the least, inextricably intertwined with the activity of the central nervous system. One of the characteristics of Hans Selye's life-long work and popularized writings on stress (Selye, 1975) was his constant emphasis upon the adrenal and pituitary hormones and the autonomic nervous system, as opposed to the brain, an emphasis not shared by others (Mason, 1975). Unfortunately, this approach deemphasized the role of the brain and may have been instrumental in retarding, until recently, direct and vigorous research efforts into the central nervous system handling of stress and stress-related behavior.

## The Lack of a Definition of Stress

Selye (1973, p. 2) defined stress as "a nonspecific response of the body to any demand." The demand can be pleasant or unpleasant. He further defined the nonspecific response when he described the "general adaptation syndrome," which includes symptoms such as tachycardia, hypothermia, hypotonia, and hypertension. In Selye's view, stress is the result of a "local reaction to a local change," resulting in activation of an unidentified "first mediator" that causes the general adaptation syndrome. The brain is not involved, since "denervated rats still show the classic syndrome when put under stress" and "stress occurs under deep anaesthesia or after deafferentation of the hypothalmus in mammals, as well as in lower forms of life that have no nervous system" (Selye, 1973, p. 6, 9). Claims of that sort by Selye, unconvincing at best, discouraged clinical and basic science research efforts toward elucidating the role of the central nervous system in stress. It was the flag under which an army of publications deluged the stress literature for several decades, looking always and only for the peripheral manifestations of stress such as changes in heart rate, blood pressure, galvanic skin resistance, pupillary size, and many other inconsistent and often irrelevant signs (Trumbull & Appley, 1967; McGrath, 1970c). These came to be regarded as absolute tests for the presence or absence of stress.

Another very typical definition of stress is "the behavioral and physiological response to actual or impending aversive stimuli" (Anisman & Zacharko, 1982, p. 89).

As one can readily see, these two definitions may be contradictory ("pleasant" demands are not adversive); further, when one seeks to obtain further elaboration of key words (e.g., "stimuli," "response," or "demand"), there is none that allows a discriminating consistent, functional definition. Most authors agree that there simply is no adequate single definition of stress (Pepitone, 1967; Hamburg & Elliot, 1981; Anisman & Zacharko, 1982). Indeed, there are those who feel that stress is synonomous with arousal and therefore does not even constitute a separate phenomenon (Mason, 1975). Murison and Ursin (1982, p. 115) offered the following definition: "The simplest operational definition of stress, therefore, is that it is the process which produces a change in your own favorite physiological parameter." For the purposes of this project, the definition of stress put forth by Anisman and Zacharko will be accepted. Event-related brain potentials will be used as our "favorite physiological parameter."

## Involvement of the Central Nervous System in Stress

While it continues to be rather difficult to define stress from a clinical point of view, there seems to be increasing acknowledgement among investigators that the central nervous system plays the key role in the generation, perception, mediation, and control of stress. "Any way one looks at it, though, the initial stressor must be viewed as having neuronal consequences..." (Anisman & Zacharko, 1982, p. 125). Heninger (1982, p. 107) states that "behavior is a consequence of nervous activity; thus, behavioral attempts to cope with stress are only one visible aspect of a large number of adaptive mechanisms in

response to stress." Pribram and McGinness (1982, p. 497) feel that "hippocampus is seen as playing a critical role in the pituitary/adrenal 'stress' system...". In a review of the biobehavioral science research related to stress, Hamburg and Elliot (1981) state:

> The catecholamines, which are found both in the adrenal and in several parts of the brain, have long been associated with stress . . . Another clearly relevant group of compounds are the endorphins, which are endogenous, morphine-like peptides that are probably involved in brain regulation of the perception of an response to pain. Also of interest are recent studies which indicate that the brain may influence immune function . . . Studies suggest that stressors are risk factors for a variety of infections . . . (p. 417)

Cohen (1982, p. 279) points out that "it is increasingly evident that an extensive network of central nervous system, autonomic nervous system, endocrine, neuroregulator, opioid peptide, and immunologic responses may be involved." All of these authors cite many references to substantiate their claims.

## Brain Potentials and Brain Function

As evidenced above, there is a large and growing body of literature to support the concept that the brain is intimately involved in the generation, perception, mediation, and control of stress. Since EP/ERP and EF/ERF measurements reflect the state of the electrical potentials and magnetic fields of the brain respectively, perhaps they can be used to either detect or further analyze stress in humans. Shagass (1972c, p. 111) states that "our basic assumption is that disordered behavior is associated with altered cerebral excitability and that some aspects of these excitability changes will be reflected in evoked responses." There is some support for this approach.

Both EP/ERPs and EF/ERFs are preceded by either the propagation of action potentials or the spread of a graded potential (Kaufman & Williamson, 1982). In either case, an intracellular axial current along the length of the involved portion of the neuron results. In the case of EP/ERPs, the potential being measured is related to the extracellular volume current that subsequently follows. EF/ERFs, on the other hand, may reflect the intracellular axial current. Both methods would be expected to mirror changes in the activity of large focal populations of neurons and, hence, be correlated with focal brain activity. Indeed, when evoked potentials are recorded over an appropriate area of the sensory cortex, one sees a clearcut response to the sensory stimulus (Desmedt, 1979). Likewise, when the stimulus is internal in origin, consisting of information from past experiences or anticipation in preparation for decision making, significant changes also take place in the event-related potentials. While it is relatively easy to detect these changes, it is enormously difficult to analyze them as to their actual brain mechanism. Determining exactly what areas of the brain are involved at any given moment, what role they serve, and how they relate to and can be modified by all of the various external and internal stimulus parameters remains an elusive goal of research in the area.

## Brain Potentials and Stress

Since stress is a psychophysiological state of the brain that involves many functional areas, connecting pathways, and electrical and chemical changes, it is likely to be accompanied by highly complex and variable changes in the EP/ERPs. The problem that can be anticipated is not in being unable to detect a change at all but, rather, in detecting some specific pattern of change that is typical of stress. Hopefully, several different

EP/ERP patterns will be found, each of which can be related to a different type of stress response. From an intuitive point of view, this is a feasible objective, provided one seeks only large, qualitative EP/ERP differences. It would not be reasonable to expect that present knowledge and techniques would allow one to detect bioelectrically that a component of a current EP/ERP response to stress is actually the result of an incident that took place several years ago. On the other hand, it may be possible to detect the difference between the way the brain mediates a calm, effective coping response to stress, on the one hand, and a highly emotional explosion of fear and anxiety on the other hand. In the latter case, a large segment of brain might be intensively activated over a significant period of time; in the former, that area (or areas) might be relatively quiescent.

Few attempts have been made, thus far, to characterize the EP/ERP changes during stress. Shagass (1972a) suggested that the later portion of the ERP may be diminished in amplitude under conditions producing stress or anxiety. McCallum (1979) relates that Sano reported slowly changing potentials during stress. Callaway (1975) speculates about a U-shaped relation between the effects of stress and the amplitude of the later portion of the ERP; as stress intensity increases, so does the ERP amplitude, up to a point. Further increases in the level of stress cause a decline in amplitude. The current situation, then, is one in which a strong need exists for being able to predict the type of reactions likely to be manifested by a given individual when stressed. Considering what is known of stress physiology, the utilization of EP/ERPs and EF/ERFs may provide a practical tool for making such predictions feasible, at least at a rudimentary level.

## Predicting Responses to Stress

Individuals vary in their types of responses to stress, and there is some degree of consistency to the type of response of a given individual. It has been suggested that the type of response manifested by a given stressed individual is related to his basic personality (Chesney & Rosenman, 1983; Horowitz, 1976). If the latter relationship is valid, it raises the possibility that EP/ERP and EF/ERF measurements obtained in the baseline state (i.e., while the subject is not being stressed) could be used to predict stress responses indirectly, by virtue of their correlation with classifications of basic personalities. This would, in turn, require that there are correlations between classes of personalities and EP/ERPs.

### Personality Types

A number of taxonomies have been introduced to partition personalities into classes that are clinically relevant. Some, like the "Type A and Type B" behavioral patterns (Chesney & Rosenman, 1983), are oriented primarily toward matching personalities with certain patterns of clinical responses to stress. Other, more general schemes have been applied to the problem of enumerating a complete set of elementary personality traits and developing questionnaires to detect reliably the degree to which any of those traits are present in a given individual. One of these, the Eysenck Personality Inventory (EPI) and Questionnaire (EPQ) (EDITS, 1975) has specifically addressed the problems of correlating personality trait measurements with reactions to stress. The "neuroticism factor" of the EPI is described as a measurable variable that "implies low tolerance for stress whether it be physical as in painful situations, or psychological as in conflict or 'frustration' situations" (Eysenck, 1967, p. 41).

There is good reason to expect good correlations between stress reactions and the results of personality tests. As pointed out previously, certain kinds of people do seem to

react in correspondingly stereotyped ways to stress. Further, it is generally acknowledged that stress responses are shaped by "physiological status, genetic traits, current expectations, past experiences.." (Hamburg & Elliott, 1981, p. 414); yet each of these is a vital determining factor of what is called the personality.

Note that personality questionnaires assess the tendency to respond to a stressful situation in a general way. They do not answer the question as to whether or not the security guard will draw his revolver and shoot the intruder. They do attempt to predict whether there is a strong likelihood that, on the one hand, the guard will panic and "fall apart" or, on the other hand, will maintain control and manifest attempts to cope with the situation on the basis of previous and current experiences. The "N" (neuroticism) factor of the EPI is reported to be useful in this regard (Eysenck & Eysenck, 1969). Eysenck (1967) was careful to point out that there are:

> complex interactions between amount of drive present, task difficulty, stress experience, and the various other independent variables . . . Proper quantification of all these variables is essential before confident predictions can be made in the individual case. Without such quantification the theory may still be useful in predicting performance at extreme ends of the scale . . . . (p. 52)

Of course, such tests cannot be repeated too often without becoming ineffective, and they are more or less susceptible to either deliberate or inadvertent misrepresentations on the part of the subject. Further, they require at least a minimum of cooperation, communication, and understanding on the part of the subject. This suggests that they would not be as useful as one might hope for predicting stress responses. As will be outlined later, personality tests can, however, be employed as an independent measure within a battery of measurements needed for prediction.

### Personality and Brain Potentials

If one accepts that there is a relationship between (1) personality traits and individual responses to stressful situations, (2) individual responses to stressful situations and the state of that portion of the central nervous system (CNS) that embodies the response to stress, and (3) that portion of the CNS that embodies the response to stress and EP/ERP waveforms, then correlations between personality traits (as revealed, for example, on the EPI) and EP/ERPs should be detectable.

O'Connor (1980) found small differences between subjects with introvert and extravert personalities in amplitudes and sites of origin of their EPs. Shagass (1972a) found a U-shaped relationship between evoked potential amplitude and age with greater amplitudes in childhood and after age 40. He speculated that this relationship behaves differently in extraverts as opposed to introverts in that extraverts may manifest amplitudes, corresponding to those of introverts, at older ages. Friedman and Meares (1979) stated that extraverts show larger amplitudes of the late components of the auditory-evoked potentials, as opposed to the findings of Stelmack, Achorn, and Michaud (1977), which showed greater amplitudes in introverts.

These studies indicate that further explorations of the relationships between personality traits and static EP/ERP patterns might prove fruitful (Eysenck, 1967, p. 261) in the search for predictors of responses to stress. There are, however, several reasons for preferentially pursuing another approach. To begin with, the subject's response to a personality questionnaire may not be honest and/or valid, as outlined previously. Furthermore, the extent to which the EPI neuroticism factor is an indicator of a stress-response

trait is not at all clear, since the neuroticism factor itself may be significantly influenced by the current state of the subject's level of stress (Eysenck & Eysenck, 1969; Hare, Payne, Laurence, & Tawnsley, 1972) and thus reflect the influence of both genotypic and environmental state components.

Baseline EP/ERP measurements alone cannot suffice in attempting to measure/predict stress, even when supplemented by personality assessment questionnaires (McGrath, 1970c). Instead, EP/ERP measurements must also be obtained, for comparison, while the subject is being actively stressed. This view conforms with that of Eysenck (1967), who pointed out that:

> Different reactor systems do not necessarily react in similar ways to stress . . . some measures show significant differences between normals and neurotics during rest, anticipation, stress, and poststress periods. Some measures show differences during all stages except under stress; yet other measures show differences only during stress, and . . . others again yield their main differences during post stress periods. (p. 73)

Further support for this kind of approach consists of experimental neurochemical studies showing that, during stress, selected CNS neurons can be transiently activated with associated chemical changes of the kind that would be expected to affect EP/ERP patterns (Anisman & Zacharko, 1982). It is, therefore, possible that only during stress will there occur specific EP/ERP changes in a subject that can be used to predict the subject's behavioral responses to future stress.

### Methods for Experimentally Provoking Stress

This section examines the ways in which someone might be subjected to experimentally induced stress.

Physical and psychological stressors are so diverse in nature that it is hard to imagine any single stressor that would be representative in affecting all subjects in the same way or to the same degree. Moreover, the more effective stressors tend to be those that some might consider to be unethical, such as stress protocols involving the use of electric shocks or deliberately misleading and threatening statements. An acceptable stressor task, for our purposes, is one that (1) can cause no harm, (2) can effectively and uniformly stress all subjects, (3) can be implemented quickly, (4) has short-lived effects, (5) can be applied in a laboratory environment where the subject has little freedom to move, (6) can be used repeatedly with the same effects each time, (7) will not interfere with bioelectrical and biomagnetic recording, and (8) resembles the psychological effect we seek to study (as opposed to more mechanical-physiological "stressors" such as heat, cold-pressors, etc.). Since no known experimental stressor currently fulfills all these criteria, any work of this kind involves using the most reasonable compromise that fits the demands of the experimental situation. However, being prepared to compromise still does not resolve the dilemma. For example, in a statement that a stressor "effectively and uniformly stresses all subjects," what is meant by the word "stresses"? From a practical point of view, what exactly is the stressor supposed to do? How does it achieve its objective? Should it cause a subjective feeling of some sort in the subject, a degradation in the performance of some task, or a change in some physiological measurement? Should it do these things by overloading the subject with a demanding task that is impossible for him to complete, by pain, by exposure to "frightening" scenes, or by conflicting and inconsistent tasks?

Stressors: The Role of Arousal. As one might expect, there is no agreement in the literature as to what constitutes a "stressor," since there is no generally accepted operational definition of what constitutes "stress." As previously noted, some believe that stress and arousal are equivalent (Mason, 1975). If this view of stress as equivalent to arousal is true, then the implication is that a stressor (and only a stressor) must always cause arousal. Others regard arousal as one of the consequences of stress or, in fact, as an essential component thereof (Gray, 1982). This view, in turn, is rebutted by the increasing acceptance of boredom and monotony as stressors (McGrath, 1970c; Appley & Trumbull, 1967); for example, in the case of security guards. Also, this view makes it difficult to explain those cases where chronic severe stress continues beyond the point of exhaustion, at which point fatigue, depression, and inactivation dominate the picture as opposed to arousal (Sanders, 1983). It seems clear that the association between arousal and stress is intimate and strong, but it is not universal; therefore, one cannot legitimately use the level of arousal, or any other effect of arousal, as a measure of stress (Cohen, 1967). The implication of this to stress studies using EP/ERP measurements is obvious--we must clearly differentiate between EP/ERP changes as a result of a stressor's ability to evoke arousal as opposed to its ability to evoke stress. Conversely, any study purporting to measure the effects of a stressor must closely monitor the subject's level of consciousness (arousal), as well as other variables, as possible sources of contamination.

Johnson and Lubin (1972) pointed out that "one can only guess at the number of studies that have been done using subjects who were supposed to be awake but actually dozed off or even slept through the experiment." They emphasized the need to control for changes in level of consciousness as measured by the EEG. Shagass (1972b, 1972c) discussed the effect upon the evoked potentials of alterations in the state of awareness, as correlated with EEG changes in both amplitude and frequency. So did Aleksandrova (1972, p. 107), who concluded that "the higher the alpha rhythm frequency, the shorter the latent period of nearly all EP components in the occipital and vertex regions" and "at a greater alpha rhythm amplitude, longer latent periods of EP components in the vertex region are observed." An exploratory study in the Center's laboratory using continuous EEG recording during evoked potential studies confirmed that there are marked and rapid fluctuations in the level of consciousness of the subjects that may not be readily apparent to either the subject or the technician obtaining the EP data. In short, stress cannot be regarded as equivalent to arousal; hence, a stressor cannot be defined as any stimulus that produces arousal, nor can the level of stress be measured by the level of arousal. On the contrary, in any experimental study of stress, an attempt must be made to monitor and maintain a constant level of arousal.

Detecting and Monitoring Stress. Since there is no agreement on the definition of stress according to its intrinsic mechanisms, perhaps stress can be defined as a pattern of physiologic responses. Although this approach would afford the advantage of being able to select or evaluate a potential stressor by virtue of its facility in evoking those responses, it requires selection of a proper set of responses. Activation of the adrenocortical endocrine system is not specific for stress (Mason, 1975). Autonomic nervous system activation is well known to be unreliable, to the point that others have used this unreliability as evidence of the existence of a high degree of individual specificity and intersubject variability in responding to the same stressor (Lacey, Kagan, Lacey, & Moss, 1963). Performance measures likewise are characterized as not being proper indicators for stress (Sanders, 1983). Sanders, like McGrath (1970b), has recommended that performance measures should be used only as control measures to ascertain that sufficient effort is allocated to keep performance at the optimum during the task. Indeed, if we believe that the CNS plays a role in stress and therefore in using EP/ERP measurements

to assess stress, we are placing ourselves in the curious stance of trying to select and use other physiologic or performance methods, already known to be relatively unsuccessful at detecting or measuring stress, as indicators by which to judge the efficacy of a technique suspected to be far more sensitive and selective.

Without some other reliable method of measuring stress, it will not be possible to assess the significance of an EP/ERP measurement that shows no change during a stressor test. Finding no change could mean that the stressor used was not, after all, effective. It could also mean that EP/ERP measurements are not capable of detecting changes in brain activity during stress. Finally, it could mean that the stressor is effective on most subjects but, for some reason, not on this particular subject. This last possibility implies that there may be general classes or types of stressors, and that there may be relationships between the subjects who show EP/ERP responses to a particular type of stressor and their basic personalities. For example, extraverts might tend to manifest a significant change in response to any one of a whole class of stressors, while introverts would show no change to those same stressors.

Types of Stressors. There have been a number of publications that seek to subdivide experimental stressors into classes based primarily upon protocols; for example, upon whether or not the stressor task involves time-sequencing of stimuli, the interpretation of complex information, or threats of punishment (Hackman, 1970). Little, if anything, has been published that attempts to relate classes of stressors to types of responses or personalities, except for the previously mentioned work regarding the autonomic nervous system and individual differences, as with Type A/B behavior profiles. This lack is curious, from a clinical point of view, because the existence of such classes of stressors and related classes of responders is an everyday, and often dramatic, observation. Witness the person who is "self-motivated" to the extent that he is severely stressed by his own internal demands upon his performance, compared with another person who becomes stressed mainly by more primitive external imagery and could not care less about time and task performance. The former personality often characterizes those who develop duodenal ulcers (Alexander, 1950), while the latter often seems to be the case in those who possess hysterical personalities (Horowitz, 1976).

Protocols. The implication of these observations is that it should be possible to better evaluate the effectiveness of, and response to, a particular stressor by using several stressors on each tested subject, with each stressor designed to best evoke stress in a subgroup (of the general population) characterized by a specific personality profile. This approach is not a new concept in the stress literature. Although the need for studies of this sort has often been pointed out (McGrath, 1970d), seldom have they been done. Basically, the voluminous literature on stress tasks recommended that the stressor task protocol should:

1. Include baseline evaluations of the subject.

2. Include measurements of personality assessments.

3. Include evaluations of the response to several different types of stressors.

4. Use each given type of stressor at multiple levels of intensity.

5. Include ongoing assessments of arousal, particularly EEG recording.

6. Measure responses by means of several different parameters.

7. If possible, be repeated over a period of time, on the same subjects.

8. Be implemented in the most meticulously controlled environment as is reasonable for the test and the objectives of the study.

9. Consume a reasonably short period of time so as to avoid marked changes in level of consciousness and in other physiological variables.

Analysis of Data

The manner of data interpretation warrants further discussion. Recall that EP/ERP data are obtained by averaging together many observations. This must be done because the bioelectric activity of interest is of very low amplitude and is often obscured by the background activity. The averaging reduces the apparent effect of the background because the background frequency is not time-locked or synchronous with the stimulus. The evoked potential, on the other hand, is synchronized to the stimulus and thereby enhanced by averaging. It is believed that the earlier components of the evoked potential (up to 100 msec) largely represent primary sensory processing (Hillyard, Picton, & Regan, 1978) and that the later components represent "cognition"; that is, the higher-level central nervous system handling of the input (e.g., various aspects of recognition, association, storage, coordination, evaluation, and other functions that are applied to or affected by the stimulus) (McCallum, 1979).

Investigators often obtain such evoked potentials, both under the "nominal" laboratory situation (baseline recordings) and during the experimental stress condition. The data are then analyzed for differences between the waveform amplitudes and latencies of the two recordings, and any differences are attributed to the effect of the situation (e.g., stress) upon the individual. This approach may have both empirical and theoretical shortcomings.

Note that, in this approach, one does not look generally at the manifestation of stress within the brain. Rather, one is looking selectively at the effect of the resultant stress upon the brain's response to a visual or auditory stimulus. This particular approach of analyzing auditory or visual stimuli may have absolutely no clinical or behavioral relevance to stress as an entity worthy of independent study.

While the evoked brain response to the visual or auditory stimulus is time-locked and is therefore enhanced by averaging, the brain's response to stress is not time-locked and is not transient. It is present and changing all the time that the evoked responses are being obtained; therefore, averaging techniques will not necessarily represent meaningful information specifically related to stress. In particular, the "background activity" that is thereby averaged out may be the very same activity that is most meaningful and that should be captured and analyzed (Callaway, 1979). While empirical, statistical explorations of this sort might luckily hit upon some consistent relationship, more direct methods are desirable. Therefore, in addition to the previous recommendations, one should at least explore the feasibility of alternative approaches. One such approach would be to eliminate the visual/auditory stimulus, and, instead, consider the possibility of using a time-locked stimulus consisting of the stressor itself. The stressor would obviously have to be one that has rapid onset, short duration, and is repeatable so as to enable its resulting EP/ERP waveforms to survive and even be enhanced by the technique of averaging. As an example, the stimuli could consist of a sequence of pictures flashed upon a screen at controlled intervals of time. The pictures could be selected so as to evoke various degrees of stressful feelings in the subject. This particular example,

however, would have the disadvantage of also causing visual-evoked cerebral potentials. Finding a suitable stimulus to meet these qualifications is, admittedly, a challenge, but it appears to be a promising approach.

Another approach would be to study the responses to stress as manifested in topographical EEG displays/analyses, a technique that allows one to dispense with all stimuli other than the stressor (Livanov, 1977).

Data Displays

The current format for displaying the evoked potential, where amplitude changes are plotted against time for each of the different recording sites, presents the data in a way that makes it difficult for the investigator to discern dynamic anatomical-temporal fluctuations in EP/ERP amplitudes. Vaughan (1979) states that:

> There is an intrinsic ambiguity in the interpretation of scalp potential amplitude variations--they may reflect either changes in amount or extent of neural activity, an ambiguity which can be resolved only by detailed mapping of the surface potential distribution.
>
> It is evident, therefore, that quantitative analyses of the ERP must evaluate not only the magnitude and timing of their components, but also their spatial distribution ( p. 444).

Further, Vaughan (1982) urged that topographic data be used to interpret the surface recorded ERP distributions in terms of their intracranial sources. Duffy (1982, p. 191) concurs with Vaughan:

> The interpretation or evaluation of multichannel EP data requires analysis of large volumes of data across both space and time. We propose that the inherent difficulties involved in making such spatio-temporal correlations by unaided visual inspection place constraints on both the clinical utility and research applicability of EP. The topographic mapping system . . . reduces the dimensionality of data and offers . . . major advantages.

Topographical Displays

Temporal mapping has been employed for many years by increasing numbers of investigators (Livanov, 1977; Ragot & Remond, 1979). By using displays wherein different colors and hues represent different polarities and amplitudes, one can even more easily represent and analyze the origin and spread over the surface of the brain of EP/ERP changes that take place over a period of time following the stimulus. Such displays have been used both with EEG and EP/ERP studies and also have incorporated statistical applications to the data before they are displayed (Duffy, 1982).

This approach is referred to as "color topographical displays." The screen is partitioned in such a way as to represent a diagram of the cortical surface of the brain. All the cortical regions are thereby represented simultaneously. As time elapses, the different amplitudes of the electric fields over each region are indicated by different colors and hues. Most displays of this sort allow at least 256 different hues, so that the spread of, for example, a positive-polarity high-amplitude peak can be presented in a dynamic, movie-like or cartoon fashion as it first appears in one location and then travels to a different cortical location in succeeding time intervals.

The benefits derived from neurochemical studies are well-known. They are responsible for much of our current knowledge of brain function. The limitations of neurochemical studies, however, are also well-known. It is information ordinarily derived from experimental animal material, autopsies, or invasive procedures. The process of obtaining or analyzing the material often destroys or significantly alters the function of its structures. Further, knowing that a chemical is present at a specific location does not necessarily tell its function there or the function of that part of the brain. It is a static measurement in that it tells little of the moment-to-moment spread of control or data through the brain, and, hence, little of the overall purpose or mechanism of neuronal activities. While a number of different models of brain function have been proferred, even in regard to "anxiety" (Gray, 1982) and "stress" (Anisman & Zacharko, 1982), those models all hypothesize and require a very selective sequence of discharging in groups of neurons, whose effects are transmitted over specific pathways to and from specific brain areas and in a specific timed sequence. Confirmatory evidence for any such model has to come from studies that are noninvasive and dynamic, such as EP/ERP measurements. However, the evidence will be helpful only to the extent that it provides information now lacking. It is necessary to know which brain areas are active, at what time, and in what sequence the information spreads over which specific pathways from one area to the next.

According to Nebylitsyn (1972), efforts in Russia since the time of Pavlov to explain the properties of the central nervous system from either a unified point of view, on the one hand, or a "partial, regional" point of view, on the other hand, were unsuccessful. He postulated that it was not reasonable that brain functions could be subdivided into three or four major regional properties, as Pavlov had anticipated. On the contrary, he perceived the neurophysiological parameters of behavior to be far more complex, composed of a larger number of smaller regions, each of which is primary for some function.

> The level of one or another parameter of the prefrontal cortex may not, for example, coincide functionally with that of the same parameter measured for the medio-basal region of the frontal lobes or for the limbic formations. Factual information relevant to problems of this kind will, however, only be gained by experimental investigations involving the application of methods yet to be worked out, and which will permit us to establish the characteristics of activity in spatially different nervous structures in the regulatory system. (p. 412)

Nebylitsyn found interesting the topographical EEG studies by Livanov (1977) showing that methods of this sort could be used to analyze intellectual operations. Nebylitsyn concluded that:

> This approach, in its turn, opens perspectives for the creation of a psychophysiologically-based system of personnel selection tests and for the elaboration of the psychophysiological aspects of the theory of human reliability in complex working conditions (p. 414).

Indeed, Livanov (1977) was able to differentiate individuals, according to the difficulty they encountered in solving mentally an arithmetic problem, by virtue of run-time topographical analysis.

Cognitive and emotional activities are relatively long events. They are undoubtedly highly complex, involving repeated interactions among many separate parts of the brain in a complicated sequence of events. It is, therefore, highly unlikely that one can ever begin to understand the process by looking at the activity of only one part of the brain at one

time. On the contrary, a method must be used that presents the information in a way so that answers can be found to questions such as those listed below:

1. Where in the brain does the first visible response to stress (in this person) seem to appear?

2. Where does it go from there?

3. Does the pattern differ among subjects?

4. Are there groupings of subjects possessing similar patterns?

5. Do the patterns differ regarding the immediate effects of stress or the reactions to stress?

6. Do those groupings correspond to personality assessment and/or behavior responses?

7. Are there patterns consistent with any of our models of stress?

Simply looking at a large numerical tabulation of amplitudes or latencies will not readily accomplish this, nor will statistical compilation performed upon two or more "curves" or visual "curve" inspections. Color topographical displays, on the other hand, are well suited to this purpose.

At this time, color topographical analysis cannot be applied to data from EF/ERF (magnetic field) measurements and, therefore, can be used only in EP/ERP measurements. This is because the magnetic sensors are large and cumbersome, using liquid helium for cooling purposes. They do not allow multiple independent probes to be used simultaneously on the subject. The likelihood exists that this limitation will be overcome in the next few years. Meanwhile, studies on stress of the sort with which we are concerned are best confined to EP/ERP measurements. Separate studies may continue on the biomagnetic-bioelectric comparisons and on the mechanisms of the origin of biomagnetic activity, until more suitable equipment is developed. At that point in time, the topographical techniques can be easily adapted to this newer technology.

## Testing for Stress, Stressors, and Individual Differences

### Preliminary Work

A small-sample prototype of a stress-task protocol was conducted on three subjects at the Center during the summer of 1981. It was done, realizing the almost unlimited criticisms to which it would be susceptible, simply to explore the feasibility and promise of that approach in conjunction with color topographical displays. Considerable constraints were imposed at that time upon the protocol as the result of the then-current computer hardware, which lacked sufficient main memory and secondary storage capacity to accommodate the large amount of data that needed to be manipulated. Nonetheless, the displays were found to be easily and quickly interpreted. The stressor was effective in causing marked changes in the pattern of EP/ERPs across the scalp. Differences in these patterns among the subjects were profound. It would be premature to interpret the results further, except to conclude that this kind of approach is not only feasible but also highly promising.

## The Future

Current theoretical models of brain function, while of great interest, seem to have reached an impasse characterized by contradictions and a search for solutions that only new data can supply. For example, Riss (1983), who developed a computer model of human visual processing, feels that magnetoencephalography represents the only noninvasive tool now available to clarify the sequence of activation of the different foci he has identified as a part of the visual process. Also, Zuckerman (1982) stated that studies "looking for the biological correlates of the psychological variable . . . can only approach causation through techniques such as path analysis . . . " The derivation of topographical information from EP/ERP/EEG studies of stress represents the kind of approach that can be adapted to the study of visual processes, as well as other brain functions, particularly those of cognitive nature. The application of this approach will hopefully lead to a greater understanding of brain functions generally and also as they vary from individual to individual under specific circumstances. While this largely empirical approach can be expected to yield significant new and pertinent information about the brain, personality, and behavior, one should not neglect efforts that are directed toward understanding conceptually how the brain might handle "information processing" in circumstances such as stress. In particular, computer simulation and emulation models, expert systems, and other theoretical endeavors in the realm of artificial intelligence (AI) can be quite useful when developed in conjunction with information learned from topographical EP/ERP/EEG stress protocol approaches. They can provide the framework that will enable researchers to better understand and explain empirically derived data and to guide them in further applying such tools as color topography. Newell (1983) has expressed this well:

> AI would appear to be at the mercy of the immense gulf that continues to separate psychology and the biology of the brain. As each field continues to progress--which both do dramatically--hopes continually spring up for new bridging connections. No doubt at some point the permanent bridge will get built. So far, although each increment of progress seems real, the gap remains disappointingly large.
>
> It is possible that AI has a major contribution to make to this by exploring basic computational structures at a level that makes contact with neural systems.

A high-speed, 32-bit, large-capacity, stand-alone computer will become available for use within several months. With the anticipated acquisition of a color monitor and suitable software, the Center's laboratory will be in a position of being able to implement a well controlled study dealing with the ability of EP/ERP topographical analyses to predict future job performance under stress and to explore the possibility of bridging the gap between psychology (stress) and biology (EPs/ERPs) by using computer-based models.

# RECOMMENDATIONS

The following recommendations are made for a research protocol for ascertaining whether measurements of brain activity can be used to predict performance under stress.

1. Ideally, subjects should be in residence at the testing center from at least the prior evening to maintain some control over the environment. Too often, subjects violate the rules regarding sleep, food ingestion, etc. Since this cannot be implemented at NAVPERSRANDCEN, greater effort must be placed upon emphasizing the importance of

any restrictions in these areas and adequately interviewing subjects about adherence to them prior to testing.

2. Personality testing, using the EPI/EPQ should be done, preferably on a separate day prior to testing.

3. Subjects should be available for repeated testing at appropriate intervals. Considerable efforts should be made to obtain a thoroughly representative group of subjects. At the very least, sufficient personal information must be obtained so that the subject population can be characterized in detail (i.e., gender, age, work, diet, medications, health, mental state, visual and auditory acuity, and so on).

4. Recording sessions should involve the following factors:

a. Multiple electrodes (8 channels at the very least) must be used.

b. Both bipolar and monopolar recording should be considered. Monopolar recording provides a more accurate reflection of the local amplitudes and frequencies, whereas bipolar recording facilitates the recognition of extracerebral artifacts and local activity relative to other cerebral locations. Some further exploratory studies might be of benefit regarding the selection of specific reference leads and montages. The literature seems to favor monopolar references to the ear leads.

c. Ongoing, continuous EEG recording must be used to assess the subject's state of alertness (refer to the previous discussion on stress vs. arousal).

d. The subject should be in a comfortable sitting position and be vigorously alerted between all runs, with lights turned on, conversation, novel noises, etc. The room must be kept cool to facilitate alertness. The technician should make notes, in conjunction with time-markers during the recordings, with reference to the subject's level of alertness.

e. Consideration should be given to checkerboard-reversal stimuli rather than light flashes or static checkerboards since this seems to be more and more the "industry standard" in the effort to achieve reproducible waveforms (Starr, Sohmer, & Celesia, 1978).

f. Continuous EKG (heart rate) monitoring should be done throughout the testing so as to have available an additional and independent measurement of stress, even though not fully reliable (Kak, 1981).

g. Testing should be preceded by revisions to existent computer software so as to allow more rapid employment of the testing procedures.

h. The test should be partitioned as follows:

(1) Baseline recording, followed by Stressor #1 recordings:

(a) Low intensity followed by a brief rest interval.
(b) Medium intensity followed by a brief rest interval.
(c) High intensity followed by a brief rest interval.

(2) Baseline recording, followed by Stressor #2 recordings:

(a) Low intensity followed by a brief rest interval.
(b) Medium intensity followed by a brief rest interval.
(c) High intensity followed by a brief rest interval.

i. Stressor #1 should be a timed, cognitive, performance task requiring little, if any, subject movement. The cube-counting task is ideal here, particularly since this laboratory has conducted, over the past few years, a large number of studies that have incorporated an EP/ERP cube-counting performance task. During this task, the subjects are presented with drawings of various numbers and configurations of three-dimensional stacks of cubes. They are instructed to count accurately the number of cubes represented in each drawing within a fixed amount of time. Successive drawings are more complex and therefore more difficult and "stressing" to count within the required amount of time. The resulting cube-count scores can be used to assess performance effort, while simultaneously obtained heart rate and EP/ERP data can be used to measure and analyze the response to stress. The procedure is amenable to the use of minimal deception to enhance the stress; for example, by informing the subject that performance thus far is poor. This task requires little motor movement, provides ways of assessing performance effort, allows for multiple levels of difficulty, is easily repeatable, is not harmful to the subject, is easily reproduced from subject to subject, does not interfere with auditory-evoked potential studies, consumes a short period of time, and would be expected to cause stress in a subset of the population (i.e., those who are self-motivated and highly conscientious individuals), thereby inviting correlation studies regarding personality traits. The Stroop test, and others of this sort, could also be considered. Here, as one example, the subject is shown, on a screen, the name of a color. The screen image is also colored, but the color of the screen image does not necessarily match that of the name. The subject's task is to select one out of a set of objects where the object's color coincides with that of the name on the screen but not necessarily that of the image's color. The Stroop test may also be timed and shares many of the advantages of the cube-counting task. Stressor #2 should be of a completely different nature, such as pictorial presentations of potentially disturbing photographs intermixed with neutral scenes.

j. Magnetic studies should be done separately so as not to introduce further constraints on the stress protocol methods.

k. The testing should employ summated auditory-evoked potentials as targets for analysis, since this can be implemented with little disturbance of conscious effort upon task performance.

l. Analysis of the data should include the technique of color topography.

m. Subjects should be interviewed (or fill out a questionnaire as previously developed at the Center) after testing, in order to independently assess the subjective attitudes and degree of stress during the testing procedures.

n. A separate protocol should be developed and implemented wherein evoked potentials are not used. Instead, the stressor itself should be the time-locked stimulus and either part of a single epoch study or used as part of a sequence of stressors for summations. Pictorial displays as alluded to above could be adapted for this. Perhaps this technique of equating the stressor with the time-locked stimulus will, in the end, prove to be more meaningful and useful than any other.

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